

**ESTIMATION OF ORIGIN-DESTINATION AIR TRAFFIC FLOWS FROM
AIR TRANSPORT MOVEMENT DATA:
AN APPLICATION TO INDIAN DOMESTIC AIRPORT NETWORK SYSTEM**

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ABSTRACT

The objective of this paper is to study and estimate origin-destination (O-D) city-pair passenger air traffic based on DGCA (Director General of Civil Aviation) airport statistics and scheduled airlines data. Considering the basic lacunae of the non availability of the air passenger O-D traffic flows in the public domain, the iterative empirical procedure developed in this paper can serve as an invaluable tool for the validation of traffic forecasting models and also to assess the suitable aircraft size/ fleet composition for serving short-haul air routes. In this study, five year traffic data (2000-2004) from the Director General of Civil Aviation (DGCA, India) and schedules of domestic airlines in India has been used as the base for developing a mechanism to predict origin-destination air passenger traffic flows between airports (city-pairs) in the domestic air network. The outcome derived from this can support the academic pursuits and research efforts in air transport field.

Keywords: air transport movements, domestic airports, Origin-Destination air passenger traffic flows, embarked and disembarked load factors, available seats, scheduled airlines

1. INTRODUCTION

The flight planning of scheduled airlines includes many tasks, such as aircraft fleet selection, prediction of future need and the prospective passenger movement etc. In order to solve these varied tasks; it is pertinent to understand the traffic pattern and in this regard, the usefulness of formulation of Origin-Destination (O-D) matrix highlighting the air passenger traffic can be a useful tool in air transportation planning to find the traffic flow pattern. In this regard, it is to be borne in mind about the immediate need for the estimation of future potentials of city-pair passenger traffic as presently the air passenger O-D traffic flows are not available. This O-D traffic flows data is very much useful for the validation of traffic forecasting models and also to assess the aircraft fleet composition being deployed on city-pairs. Also, the estimation of O-D passenger matrix flows is necessary to establish the hierarchy of air transport network. The O-D city-pair air passenger traffic proposed to be evolved in this study would be an essential tool for determining suitable aircraft size which can serve short-haul regional air routes.

The data has been obtained from DGCA (Director General of Civil Aviation, India) website (<http://www.dgca.nic.in>). The data regarding airport statistics consists of number of passengers embarked and disembarked at each airport, number of aircraft movements etc. The aircraft type, seating capacity, flight frequencies, route network of operations etc. were

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compiled from operations done by various airlines during the specified time period. The approach followed in this paper to determine O-D passenger traffic flows from is helpful to arrive at O-D matrix for 314 city-pairs which otherwise is not available in public domain.

2. METHODOLOGY FOR ESTIMATING O-D TRAFFIC FLOW MATRIX

The literature reviewed indicates that (i) the fundamental element in development of air transportation is to prepare a city-pair air passenger demand matrix and (ii) in the 21st century, airlines around the world are finding that a more detailed research concerning passengers and destinations is required due to increasing competition. Many attempts have been made to identify traffic pattern. Various methods can be used to estimate the O-D matrix. These methods can be divided into three categories, viz., direct sample estimation, model estimation, and estimation from traffic flows. All these existing methods are usually used to estimate the O-D matrix considering some statistical aspects of estimation (*Rakhmat and Hiroshi 1997*). A procedure for the estimation of origin-destination (O-D) matrices for a multimodal public transit network has been attempted through a case study of the Hong Kong transit network (*Wong et al 2005*). Here, an entropy maximization procedure has been proposed to simultaneously estimate the O-D demand matrices of all favored modes, which are consistent with target data sets such as the boarding counts and line segment flows that are observed directly in the network.

In this study, the authors have collected and analyzed the basic airport statistics comprising air transport movements (atm) from DGCA which consists of aircraft movements (inbound and outbound), passenger traffic (embarked and disembarked: **Figure 1**) etc. for each airport during the period 2000 to 2004. The aircraft type, capacity, flight frequency, and route network of operations were compiled from respective scheduled airline operations and analyzed. Initially, a binary matrix of size 65x65 (65 operational airports) was prepared based on the number of airports being served by the scheduled airlines (**Table 1**).

Step 1: Calculation of load factors

The load factors (LF) pertaining to embarked and disembarked (ELF and DLF) were computed for each airport based on the number of passengers embarked or disembarked and total available seats (AS) with respect to outbound and inbound aircraft seating capacities. For example, the disembarked load factor (DLF) at an airport is the ratio of total passengers disembarked (PD) to the total seating capacity of inbound flights (AS) from that airport (**Figure 2**). In this paper, the disembarked load factors (DLF) of each (destination) airport 'j' (j=1 to N) are treated as 'Coefficient of attraction' (α_j or C_a) for that airport.

Step 2. Distribution of origin traffic to various destinations

The total outbound (embarked) passengers (PE) at each origin airport are distributed based on relative weightage (ω_j) associated with coefficient of attractions (α_j or C_a) of destination airports (j =1 to N) (**Figure 3**).

Step 3: Test for convergence

The sum of estimated passengers disembarked (EPD_j) at all destination airports 'j' (j= 1 to N) from various origins were compared with the actual passengers disembarked (PD_j) at these destinations. If the estimated and actual passenger arrivals are equal (EPD_j \approx PD_j), then the O-D matrix is acceptable; otherwise, the iterations were repeated with calibration of 'coefficient of attractions' with a suitable correction factor ' δ ' (**Figure 3**) as under:

Step 4: Correction factor (δ_j)

New ' α_j ' or ' C_a ' is obtained by multiplying the previous ' α_j ' or ' C_a ' with a correction factor δ_j . The δ_j is the ratio of PD_j and EPD_j . The process is repeated till the estimated passengers embarked are within the error limit of $\pm 1\%$ to 5% , which is generally allowable/ acceptable in estimation of decision variables in the transportation engineering.

The approach followed for estimation of O-D air passenger traffic flows has been demonstrated through a case study. The methodology has been implemented in Microsoft Excel environment (error limits observed are $\pm 1.3\%$) and the development of a code in MATLAB based on this approach is under progress. The salient features of available data, initial calculations of input data and formulation of the problem are briefly outlined as under:

1. Available data/ input data

- Air Transport movements: DGCA data
 - Outbound (embarked) passenger traffic (PE) for each airport
 - Inbound (disembarked) passenger traffic (PD) for each airport
 - Route network of operations
- Data from scheduled airline operations
 - Aircraft type and seating capacity (S)
 - Flight frequency (F)
 - Route network of operations

2. Initial Calculations

- Binary matrix based on the number airports being served (65x65 size)
- Total available seats (Total capacity of inbound/ outbound flights), $AS = S \times F$
- Load factors (LF) pertaining to
 - Embarked LF (ELF) = $PE \div AS$
 - Disembarked LF (DLF or α) = $PD \div AS$

3. Formulation of the problem

$$P_{ij} = PE_i \times \omega_j$$

Where,

P_{ij} = Passenger trips from origin airport 'i' to destination airport 'j'

PE_i = Passenger trips originated from airport 'i'

ω_j = Relative weightage associated with disembarked load factor (DLF) or coefficient of attraction of destination airport 'j'

$$\omega_j = \frac{\alpha_j \times \delta_j}{\sum_{j=1}^N (\alpha_j \times \delta_j)}$$

α_j = disembarked load factor (DLF) or coefficient of attraction of destination airport 'j'

$$\alpha_j = \frac{PD_j}{AS_j}$$

δ_j = correction factor to be solved iteratively ($\delta_j = 1$ for initial iteration) = $PD_j \div EPD_j$

PD_j = Passengers disembarked at airport 'j'

EPD_j = Estimated passengers disembarked at airport 'j'

AS_j = Total seating capacity of inbound flights for airport 'j' = $S \times F$

S = Aircraft Seating capacity and F = Flight frequencies

3. CASE STUDY: DOMESTIC AIR TRANSPORT NETWORK IN INDIA

The number of airports/ aerodromes in India are 449 and out these 211 have ICAO and IATA ID. 65 airports are being served by three scheduled airlines (viz., Indian Airlines, Jet Airways and Sahara: *Sahara is now merged with Jet Airways*) during this analysis period (viz., 2000-2004). The results obtained through the methodology outlined in section are presented in **Table 2** and **3**. Here, **Table 2** and **Table 3** represent the results of initial and final iterations respectively. For example, it is evident from **Table 2** that the estimated total air passenger arrivals to Bangalore airport have been 15868 as against actual total passenger arrivals of 26058 (in 2004) amounting to huge error of 39%. Where as, the values from **Table 3** show that the estimated total air passenger arrivals to Bangalore airport were 26178 as against the actual figures of 26058 with a marginal error of 0.5%, thus converging total number of arrivals/ departures to/from an airport. A useful figure of merit to validate the iterative methodology for the prediction of city-pair passenger traffic flow has been arrived at in this paper.

Table 1: Binary O-D matrix showing connectivity between Airports

Origin		Region	Destination																			
			1	2	3	4	5	6	7	8	9	10	11	12			13	14	15	...	...	65
			AGT	BLR	BLG	CCT	MAS	KOC	CBT	HUB	HYD	MDR	MLR	PRT	PTP	TPT	TCY	TRM	VZG	...	...	...
1	Agatti	S	0	0	0	0	0	1(F)	0	0	0	0	0	0	0	0	0	0	0	...	...	...
2	Bangalore	S	0	0	0	0	1(M)	1(M)	1(F)	0	1(M)	0	1(F)	0	0	0	0	1(M)	0	...	...	...
3	Belgaum	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	...	...
4	Calicut	S	0	0	0	0	1(M)	1(F)	1(F)	0	0	0	0	0	0	0	1(F)	0	0	...	...	...
5	Chennai	S	0	1(M)	0	1(M)	0	1(M)	1(F)	0	1(M)	1(F)	0	1(M)	0	0	1(F)	1(M)	1(M)	...	...	...
6	Cochin	S	1(F)	1(M)	0	1(F)	1(M)		1(F)	0	0	0	0	0	0	0	0	1(F)	0	...	...	...
7	Coimbatore	S	0	1(F)	0	1(F)	1(F)	1(F)	0	0	0	0	0	0	0	0	0	0	0	...	...	...
8	Hubli	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	...	...
9	Hyderabad	S	0	1(M)	0	0	1(M)	0	0	0	0	0	0	0	0	1(M)	0	0	1(M)	...	...	...
10	Madurai	S	0	0	0	0	1(F)	0	0	0	0	0	0	0	0	0	0	0	0	...	...	...
11	Mangalore	S	0	1(F)	0	0	1(M)	0	0	0	0	0	0	0	0	0	0	0	0	...	...	...
12	Portblair	S	0	0	0	0	1(M)	0	0	0	0	0	0	0	0	0	0	0	0	...	...	...
	Puttaparthi	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	...	...	...
	Tirupati	S	0	0	0	0	0	0	0	0	1(M)	0	0	0	0	0	0	0	0	...	...	...
13	Trichy	S	0	0	0	1(F)	1(F)	0	0	0	0	0	0	0	0	0	0	1(F)	0	...	...	...
14	Trivandrum	S	0	1(M)	0	0	1(M)	0	0	0	0	0	0	0	0	0	1(F)	0	0	...	...	...
15	Vizag	S	0	0	0	0	1(M)	0	0	0	1(M)	0	0	0	0	0	0	0	0	...	...	...
..
..
65	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

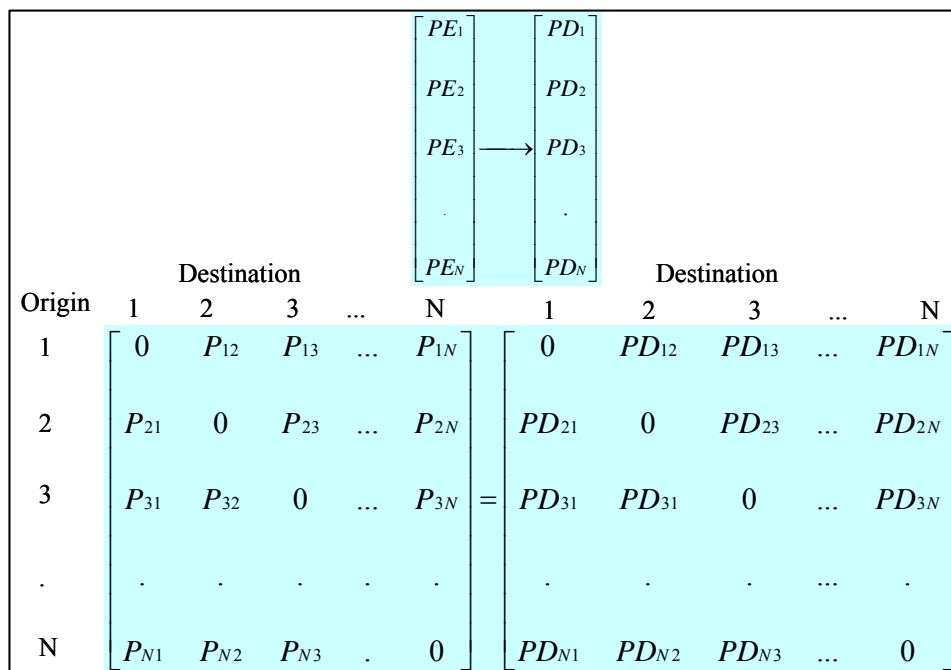


Figure 1: Notation of matrix showing passengers embarked (PE) and disembarked (PD)

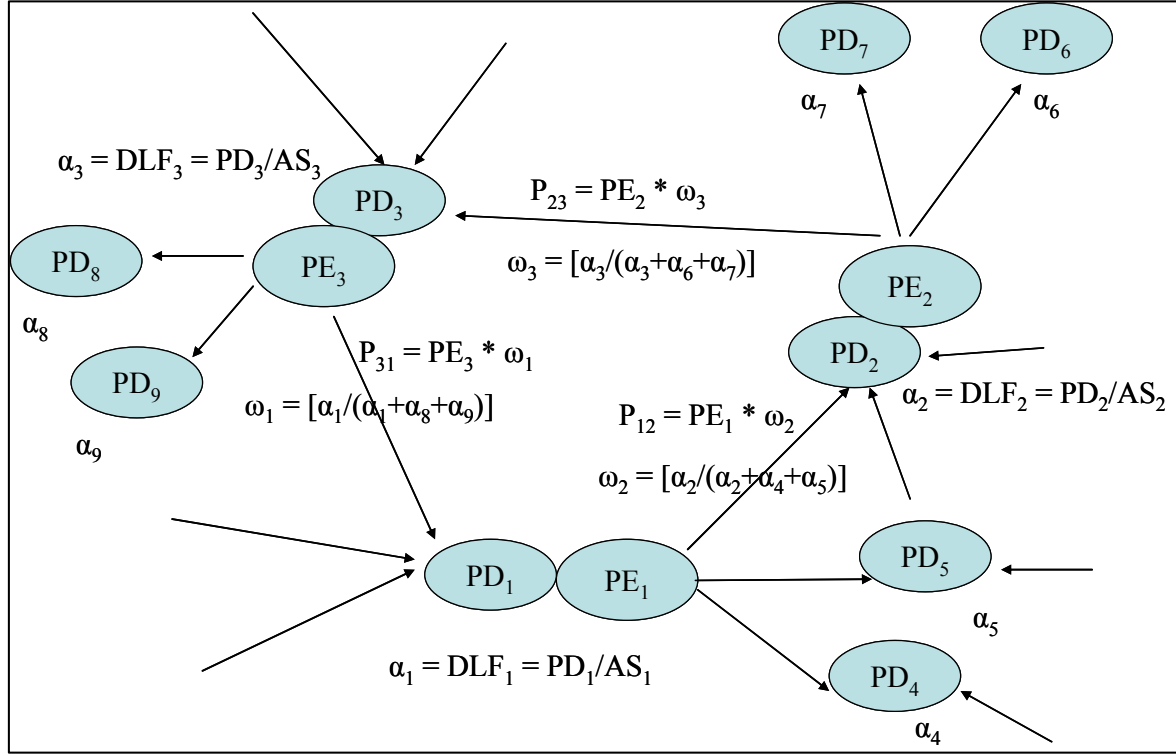


Figure 2: Calculation of disembarked load factors (DLF) for each airport

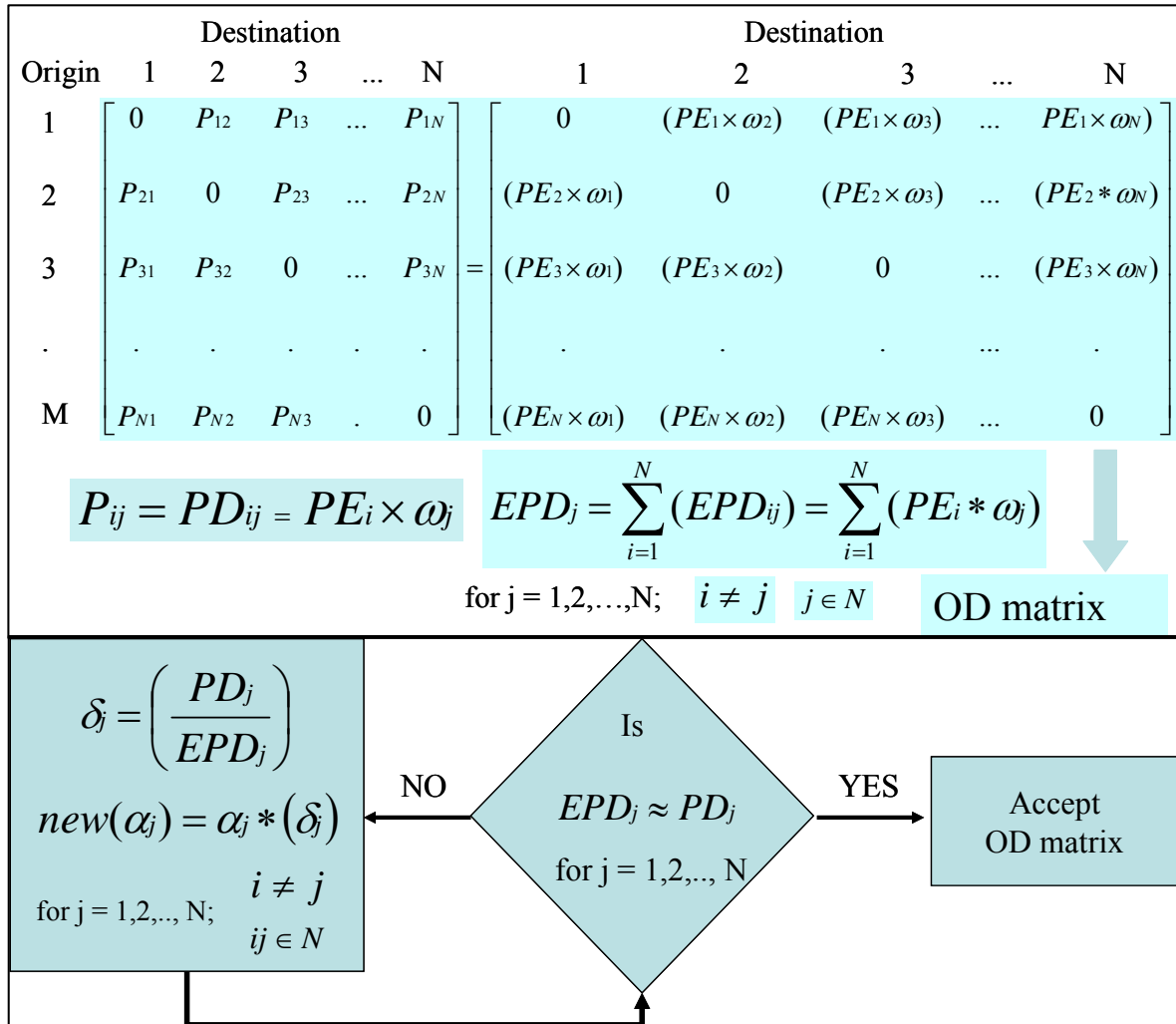


Figure 3: Approach followed for estimation of O-D air passenger traffic flow

Table 2: Estimated O-D air passenger traffic flows between Airports (Initial Iteration)

		1	2	3	4	5	6	7	8	9	10	11	12			13	14	15	..	65	
	2003-04	AGT	BLR	BLG	CCT	MAS	KOC	CBT	HUB	HYD	MDR	MLR	PRT	PTP	TPT	TCY	TRM	VZG	..	ALD	
	DLF1	0.930	0.650		0.210	0.540	0.400	0.390		0.610	0.600	0.680	0.890		0.600	0.180	0.490	0.570	...		TDLF1
1	102						102												...		0.400
2	25792					2163	1602	1562		2443		2723						1962		...	6.440
3																			...		
4	1403					282	209	203									94		...		2.690
5	24848		1967		636		1211	1180		1846	1816		2694				545	1483	1725	...	8.210
6	4571	968	677		219	562		406										510		...	4.390
7	2570		693		224	576	427													...	2.410
8																			...		
9	15015		1660			1379									1532			1456	...		5.880
10	1127					529													...		1.150
11	1982		716			595													...		1.800
12	1942					904													...		1.160
																			...		
	132									132									...		0.610
13	112				19	49												44	...		1.240
14	2396		604			501											167		...		2.580
15	1479					242				273									...		3.300
...
65	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	Est.ARL	968	15868	0	2406	15310	6042	5139	0	14431	4566	5840	4446	0	1532	806	8088	9325	..	0	306914
	actual ARL	100	26058	0	1392	23132	4473	2527	0	16079	1236	2121	1784	0	193	145	2373	1498	..	0	305904
	Err	-868	10190	0	-1014	7822	-1569	-2612	0	1648	-3330	-3719	-2662	0	-1339	-661	-5715	-7827	..	0	-1010
	Err %	-868	39	0	-73	34	-35	-103	0	10	-269	-175	-149	0	-694	-456	-241	-522	..	0	-0.3

Table 3: Estimated O-D air passenger traffic flows between Airports (Final Iteration)

Oi	Destination, Dj																				
	2004	1	2	3	4	5	6	7	8	9	10	11	12			13	14	15	..	65	
		AGT	BLR	BLG	CCT	MAS	KOC	CBT	HUB	HYD	MDR	MLR	PRT	PTP	TPT	TCY	TRM	VZG	..	ALD	
		α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_j	α_j	α_{13}	α_{14}	α_{15}	...	α_{65}	$\sum \alpha$
	Ti	0.117	0.965	0.000	0.096	0.792	0.256	0.153	0.000	0.592	0.102	0.171	0.339	0.000	0.100	0.040	0.107	0.066	..	0.000	
1	102						102												..		0.256
2	25792					2533	819	490		1893		546					341		..		8.068
3																			..		
4	1403					255	82	49									13		..		4.363
5	24848		2791		277		741	443		1713	295		981				117	308	191	..	8.592
6	4571	100	825		82	677		131										91		..	5.350
7	2570		503		50	413	133												..		4.935
8																			..		
9	15015		1855			1523									193			127	..		7.812
10	1127					247													..		3.618
11	1982		417			343													..		4.583
12	1942					1037													..		1.483
																			..		
	132									132									..		0.592
13	112				11	89												12	..		0.995
14	2396		364			299											15		..		6.358
15	1479					175				131									..		6.711
16	6986		853			701				524									..		7.903
-
32	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	..	..	..
..	54																		..	..	..
42	1447																		..	..	..
-
48	2016																		..	..	..
-
65	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	..	..	..
	Est.ARL	100	26178	0	1402	23237	4502	2543	0	16160	1248	2141	1784	0	193	145	2388	1507	..	0	306914
	actual ARL	100	26058	0	1392	23132	4473	2527	0	16079	1236	2121	1784	0	193	145	2373	1498	..	0	305904
	Error	0	-120	0	-10	-105	-29	-16	0	-81	-12	-20	0	0	0	0	-15	-9	..	0	-1010
	Error %	0.4	-0.5	0.0	-0.7	-0.5	-0.6	-0.7	0.0	-0.5	-1.0	-0.9	0.0	0.0	0.2	0.2	-0.6	-0.6	..	0.0	-0.3

Note: Est. ARL = Estimated arrivals to 'j' (i.e., EPD_j), Actual ARL = actual arrivals (PD_j)

4. SOLVING HYPOTHETICAL PROBLEM FOR ESTIMATION OF CITY-PAIR PASSENGER TRAFFIC

As the city pair/ O-D traffic data is not available, the results obtained in this study cannot be compared with the actual O-D matrix data. To assess the macroscopic aggregate accuracy of the approach, a hypothetical problem was posed based on the previous studies (*Kodanda and Rajkumar 2007*) data and solved for a five node air network (**Figure 4**) with the cost matrix (C_{ij}) and total passengers trip ends (embarked and disembarked traffic) as listed in **Table 4**.

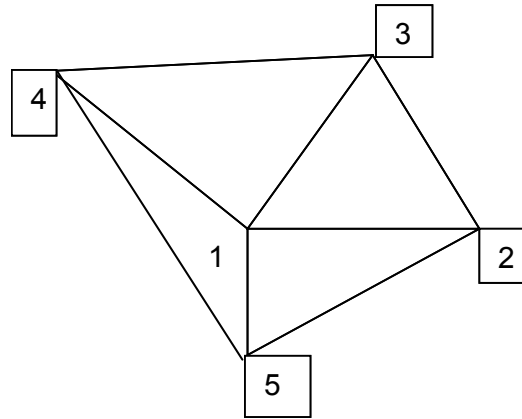


Figure 4: Five node network for solving a hypothetical problem

Table 4: Cost matrix and total Origin-Destination trips (T_i and T_j) (operating cost per flight in Indian Rupees in Lakhs)

Origin		Destination				
T_i		1	2	3	4	5
1432	1	-	0.76	1.06	1.06	0.68
1454	2	0.76	-	1.10	1.45	0.95
1063	3	1.06	1.10	-	1.20	1.38
1149	4	1.06	1.45	1.20	-	1.37
890	5	0.68	0.95	1.38	1.37	-
	T_j	1432	1432	1063	1149	890
	AS*F	2170	2170	1736	1736	1736

4.1 Using the Approach followed in this paper

As outlined in the previous sections in this paper, the total trips originated from each node are distributed to different destinations. A step by step procedure is followed to iteratively check the estimated total trip ends for convergence based on the available or actual trip ends data. The results are checked/ validated for convergence based on total number of arrivals/ departures to/from a node. The estimated or predicted O-D traffic flows are represented in **Table 5**.

Table 5: Predicted O-D air traffic flows between city pairs

a. Results of Initial Iteration								
Origin, O _i		Destination, D _j						
		1	2	3	4	5		
		α ₁	α ₂	α ₃	α ₄	α ₅		
T _i		0.6599	0.6700	0.6123	0.6619	0.5127	sum(α _j)	sum(T _{ij})
1432	1		391	357	386	299	2.4569	1432
1454	2	392		364	393	305	2.4468	1454
1063	3	280	284		281	218	2.5045	1063
1149	4	309	314	287		240	2.4550	1149
890	5	226	229		226		2.6041	890
	EPD _j	1207	1218	1007	1286	1061	5779	
	PD _j	1432	1454	1063	1149	890	5988	
	Error	225	236	56	-137	-171	209	
	Error %	15.74	16.26	5.23	-11.94	-19.21	3.49	
	δ _j	1.1868	1.1942	1.0552	0.8933	0.8388		
	new α	0.7832	0.8002	0.6461	0.5913	0.4300		

b. Results of Final Iteration								
Origin, O _i		Destination, D _j						
		1	2	3	4	5		
		α ₁	α ₂	α ₃	α ₄	α ₅		
T _i		0.8215	0.8408	0.5484	0.6055	0.4417	sum(α _j)	sum(T _{ij})
1432	1		494	322	356	260	2.4363	1432
1454	2	494		330	364	266	2.4171	1454
1063	3	322	330		238	173	2.7095	1063
1149	4	356	364	238		191	2.6523	1149
890	5	260	266	173	191		2.8161	890
	EPD _j	1432	1454	1063	1149	890	5988	5988
	PD _j	1432	1454	1063	1149	890	5988	
	Error	0	0	0	0	0	0	
	Error %	0.00	0.00	0.00	0.00	0.00	0.00	

4.2 Using Synthetic or Gravity Model Concept

Distribution models of a different kind have been developed to assist in predicting trip-distribution patterns. The best known of these models is the *gravity model*, originally generated from an analogy with Newton's gravitational law. They estimate trips for each cell in the matrix with the use of total trip ends (T_i or O_i and T_j or D_j), thereby without directly using the observed trip pattern. Therefore they are sometimes called synthetic as opposed to growth-factor models. In its simplest formulation the ***synthetic or gravity model*** assumes the following functional form (Ortuzar and Willumsen 2006):

$$T_{ij} = \kappa \times T_i \times T_j \times f(C_{ij})$$

Where,

T_{ij} = Trips between origin 'i' and destination 'j'

T_i = Trips originating at 'i'

T_j = Trips destined for 'j'

C_{ij} = Travel cost between 'i' and 'j'

f(C_{ij}) = Generalized function of travel cost with one or more parameters

κ = proportionality or balancing factor to be solved iteratively

The generalized function often called ‘deterrence or impedance function’ because it represents the disincentive to travel as distance (time) or cost increases. One of the popular version of this function $f(C_{ij}) = 1/C_{ij}^2$ is used here for solving the hypothetical problem.

$$f(C_{ij}) = \frac{1}{C_{ij}^2}$$

The iterative steps to be followed in balancing the OD matrix using synthetic or gravity model are enumerated as follows (<http://en.wikibooks.org/wiki/.....>):

1. Assess the available data T_i , T_j and C_{ij}
2. Compute $f(C_{ij})$, where $f(C_{ij}) = 1/C_{ij}^2$ [**Table 6** show the impedance matrix computed based on the cost matrix(Table 4)]
3. Iterate to balance the O-D matrix
 - a. Multiply Trips from zone ‘i’ by Trips to Zone ‘j’ by Impedance in Cell ij for all ‘ij’ [i.e., $T_i \times T_j \times f(C_{ij})$]
 - b. Sum Row Totals \check{T}_i and Sum Column Totals \check{T}_j
 - c. Multiply rows by N_i (where $N_i = T_i / \check{T}_i$)
 - d. Sum Row Totals \check{T}_i and Sum Column Totals \check{T}_j
 - e. Compare T_i and \check{T}_i , T_j and \check{T}_j [stop the iteration if within tolerance limits, Otherwise go to step (f)]
 - f. Multiply Columns by N_j (where $N_j = T_j / \check{T}_j$)
 - g. Sum Row Totals \check{T}_i and Sum Column Totals \check{T}_j
 - h. Compare T_i and \check{T}_i , T_j and \check{T}_j [stop the iteration if within tolerance limits, Otherwise go to step (c)]

Table 6: Deterrence function or impedance decay factor matrix

Impedance matrix						
Origin, O_i		Destination, D_j				
T_i		1	2	3	4	5
1432	1		1.73	0.89	0.89	2.16
1454	2	1.73		0.83	0.48	1.11
1063	3	0.89	0.83		0.69	0.53
1149	4	0.89	0.48	0.69		0.53
890	5	2.16	1.11	0.53	0.53	
	T_j	1432	1454	1063	1149	890

The results obtained using this concept/ model has been presented in **Table 7** and **Table 8** for initial and final iteration respectively.

Table 7: Predicted O-D air traffic flows between Airports through Synthetic Model (Initial Iteration)

O-D flow matrix								
Origin, O_i		Destination, D_j						
T_i		1	2	3	4	5	$\sim \check{T}_i$	$N_i = T_i / \sim \check{T}_i$
1432	1		3604792	1354767	1464372	2756228	9180159	0.000156
1454	2	3604792		1277357	794600	1433861	7110611	0.000204
1063	3	1354767	1277357		848185	496781	3977090	0.000267
1149	4	1464372	794600	848185		544840	3651997	0.000315
890	5	2756228	1433861	496781	544840		5231711	0.000170
	T_j	1432	1454	1063	1149	890	29151568	
	$\sim \check{T}_j$	9180159	7110611	3977090	3651997	5231711	20267860	
Iteration to balance O-D matrix (rows x N_i)								
Origin, O_i		Destination, D_j						
T_i		1	2	3	4	5	$\sim \check{T}_i$	$N_i = T_i / \sim \check{T}_i$
1432	1		562	211	228	430	1432	1.00
1454	2	737		261	162	293	1454	1.00
1063	3	362	341		227	133	1063	1.00
1149	4	461	250	267		171	1149	1.00
890	5	469	244	85	93		890	1.00
	T_j	1432	1454	1063	1149	890	5988	
	$\sim \check{T}_j$	2029	1398	824	710	1027	5988	
	$N_j = T_j / \sim \check{T}_j$	0.71	1.04	1.29	1.62	0.87		
		↓						

Table 8: Predicted O-D air traffic flows between Airports through Synthetic or Gravity Model (Final Iteration)

O-D matrix								
Origin, O_i		Destination, D_j						
T_i		1	2	3	4	5	$\sim \check{T}_i$	$N_i = T_i / \sim \check{T}_i$
1432	1		529	236	333	334	1432	1.00
1454	2	534		355	288	278	1454	1.00
1063	3	236	352		362	113	1063	1.00
1149	4	335	288	364		163	1149	1.00
890	5	337	277	114	163		890	1.00
	T_j	1432	1454	1063	1149	890	5988	
	$\sim \check{T}_j$	1442	1446	1067	1145	888	5988	
	$N_j = T_j / \sim \check{T}_j$	0.99	1.01	1.00	1.00	1.00		
		↓						
Iteration to balance O-D matrix (Column x N_j)								
Origin, O_i		Destination, D_j						
T_i		1	2	3	4	5	$\sim \check{T}_i$	$N_i = T_i / \sim \check{T}_i$
1432	1		532	235	334	335	1436	1.00
1454	2	530		353	289	278	1451	1.00
1063	3	235	354		363	113	1065	1.00
1149	4	333	289	362		163	1147	1.00
890	5	334	279	113	163		889	1.00
	T_j	1432	1454	1063	1149	890	5988	
	$\sim \check{T}_j$	1432	1454	1063	1149	890	5988	
	$N_j = T_j / \sim \check{T}_j$	1.00	1.00	1.00	1.00	1.00		

4.3 Comparison of results: This paper approach Vs gravity model concept

It is clear from the comparison of results in **Table 9** that the error limits observed from the approach followed in this paper are minimal. The gravity model illustrates the macroscopic relationship between places or nodes because many times it has been corroborated as a basic underlying aggregate relationship. It has been generally believed that the interaction between two locations declines with increasing distance, time or cost between them but actually it is positively associated with the degree of activity at each location. The rate of decline of the interaction (called alternatively as friction factor, or the utility or propensity function) varies by context.

Similarly, the approach followed in this paper takes into account the macroscopic view because the irrespective number of origin airports 'i' being linked to a destined airport 'j', the coefficient of attraction ' α ' is considered as same for all the trips attracted to a destined airport 'j' from various origin airports 'i'. This is one of the limiting issues of this approach like the limiting usefulness of the gravity model because of its aggregate nature. Though the policy operates at an aggregate level, more accurate analysis will retain the most detailed level of information as long as possible. As applied in an urban travel demand context, the discrete choice models with application of more expansive utility expressions are sometimes used, as is stratification by other important parameters like income levels, availability of other transport modes etc.

Table 9: Comparison of predicted O-D air traffic flows between Airports: Approach followed in this paper Vs Synthetic or gravity model (Final Iteration)

City Pair	Estimated trips: T_{1-j} (from this paper approach)	Actual traffic	%Error		Estimated Trips: T_{1-j} (from Synthetic Model)	Actual traffic	%Error
1-2	494	608	18.8		532	608	12.5
1-3	322	260	-23.8		235	260	9.6
1-4	356	347	-2.6		334	347	3.7
1-5	260	217	-19.8		335	217	-54.4
Total Trips	1432	1432	0.0		1436	1432	-0.3
2-1	494	608	18.8		530	608	12.8
2-3	330	304	-8.6		353	304	-16.1
2-4	364	325	-12.0		289	325	11.1
2-5	266	217	-22.6		278	217	-28.1
Total Trips	1454	1454	0.0		1450	1454	0.3
3-1	322	260	-23.8		235	260	9.6
3-2	330	304	-8.6		354	304	-16.4
3-4	238	260	8.5		363	260	-39.6
4-5	173	239	27.6		113	239	52.7
Total Trips	1063	1063	0.0		1065	1063	-0.2
4-1	356	347	-2.6		333	347	4.0
4-2	364	325	-12.0		289	325	11.1
4-3	238	260	8.5		362	260	-39.2
4-5	191	217	12.0		163	217	24.9
Total Trips	1149	1149	0.0		1147	1149	0.2
5-1	260	217	-19.8		334	217	-53.9
5-2	266	217	-22.6		279	217	-28.6
5-3	173	239	27.6		113	239	52.7
5-4	191	217	12.0		163	217	24.9
Total Trips	890	890	0.0		889	890	0.1

5. FINDINGS AND LIMITATIONS

The significant findings from the present study have been summarized as follows:

The approach is based on the trip distribution, which is the second component of the traditional four-step transportation planning process (viz., Trip Generation, Trip Distribution, Mode Choice, and Route Assignment). This is still an early stage research to draw definitive conclusions about the methodology or approach followed in this paper. This is only a methodology (like other intervening opportunities/ maximum likelihood models), developed purely on analytical studies, however due to lack of O-D (city pair) data, the approach cannot be validated though the results are checked/ validated for convergence based on total passengers embarked and disembarked at each airport.

Presently, 83 airports are being served/ used by nine scheduled airlines (viz., Go Air, Jet Airways, Paramount Airways, Indigo, Alliance Air, NACIL (I)/ Indian Airlines, Jetlite, Spice Jet, and Kingfisher). Considering the frenzied increase in air travel in most of the above airports, a code is being developed in MATLAB for dynamic updation of data and based on the same; use of other synthetic models will be taken up in future. However, there was a general realization of the importance of the problem and that there is a need to evolve more realistic methodologies to predict city pair air traffic flows. In the absence of matrix city-pair matrix traffic flow data, the estimated O-D matrix can be regarded as a planning tool for use in various air transportation related studies like evaluation of airport statistics, time series monitoring of traffic flows as well as selection of aircraft size and fleet planning. The first ten O-D city-pairs contributing to maximum air travel from this study analysis based on 2000-2004 data has been presented in **Table 10**. Also, the city-pairs reflecting 10 thin density sectors were shown in **Table 10**.

Table 10:
City-pairs contributing to maximum and minimum air travel pattern (year: 2004)

Max. Air Travel (10 High density sectors)			Min. Air Travel (10 Thin density sectors)		
S.No	City-Pair	Air Passenger Traffic/ week	S.No	City-Pair	Air Passenger Traffic/ week
1	Delhi - Mumbai	16953	1	Trichy - Trivandrum	12
2	Bangalore - Mumbai	9032	2	Trichy - Calicut	11
3	Chennai-Mumbai	8172	3	Raipur - Bhuvaneswar	11
4	Kolkata - Mumbai	6691	4	Ranchi - Patna	9
5	Delhi - Bangalore	5570	5	Tejpur - Dimapur	9
6	Mumbai - Hyderabad	5534	6	Varanasi - Agra	7
7	Chennai - Delhi	5018	7	Gorakhpur -Lucknow	6
8	Delhi - Kolkata	4146	8	Agra - Khajuraho	4
9	Chennai - Bangalore	2791	9	Tejpur -Jorhat	4
10	Mumbai - Goa	2758	10	Diu - Porbandar	1

Limitations:

Based on the available data (2000-2004) of DGCA, a mechanism has been developed to estimate city-pair air passenger traffic flows. This is only a methodology developed for purely analytical studies and the results are checked/ validated for convergence based on total number of arrivals/ departures to/from an airport. Though this period covers briefly the pre and post scenario of LCC (low cost carriers started operations in India in 2003), but the period from 2006 to 2008 and during 2009 has witnessed civil aviation boom and downturn (due to economic recession) respectively. Keeping the present day air traffic environment, a code is under the process of development in MATLAB by incorporating the latest air transport movement data of DGCA.

6. CONCLUSIONS

The approach that is followed to determine O-D passenger traffic flows from DGCA and airlines data, was helpful to arrive at O-D passenger traffic matrix of size 65x65 (airports), for 314 Indian city- pairs, and an useful data which otherwise is not available in the public domain. With the deregulation/‘open sky policies’ of Government of India, rapid changes have taken place in Civil Aviation in the country. Further, there is also an impact of recent economic recession. Keeping these fluctuations in view, a code is under the process of development in MATLAB environment for dynamic updating of data which can facilitate in time-series monitoring of city-pair air passenger traffic flow. This is only a methodology developed for purely analytical studies, however due to lack of sufficient traffic O-D (city-pair) data, the same cannot be validated though the results are checked/ validated for convergence based on total number of arrivals/ departures to/from an airport. The air passenger volume data obtained from this approach can be used to validate the air transport demand/ gravity models in the absence of city-pair air traffic volume data at present. The approach allows prediction to be made of O-D air passenger traffic for the available based on the data from air transport movements and thus can be of immense help in assisting the decision-making for infrastructure development, management, and laying down an airline operation/ flight frequency policy. This paper is expected to generate awareness for carrying out research work in establishing the O-D matrix flow data and collating the results with relative index of development (RID) and socio-economic activity of cities and regions in the country. In view of this, it is expected that this paper can complement the academic pursuits and research efforts in that direction.

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NOTE:

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REFERENCES AND BIBLIOGRAPHIES

Kodanda, B., Rajkumar S. Pant (2007). "Analysis and optimization of airline networks for short-haul air transportation". Proceedings and paper presented at the 11th Annual World conference of Air Transport Research Society (ATRS 2007), June 21-24, 2007, University of California, Berkeley, USA.

Ortúzar Juan de Dios., Willumsen G. Luis (2006). Modelling Transport. Third edition, John Wiley publications, 2006.

Rakhmat Ceha., Hiroshi Ohta (1997). Prediction of future origin destination matrix of air passengers by fratar and gravity models. Computers and Industrial Engineering, Vol. 33, Nos. 3-4, pp 845-848, December 1997.

Scott A. Peterson., Ian Harrington (2008). Overview of the travel demand forecasting methodology. Central Transportation Planning Staff, March 29, 2008.

Website. http://en.wikibooks.org/wiki/Fundamentals_of_Transportation/destination_choice

Website. <http://www.dgca.nic.in>

Website: http://en.wikipedia.org/wiki/Trip_distribution

Wong, K.I., Wong. S.C., Tong, C.O., Lam, W.H.K., Lo, H.K., Yang, H., Lo, H.P. (2005). Estimation of Origin-Destination Matrices for a Multimodal Public Transit Network. Journal of Advanced Transportation, Vol. 9, No. 2, Spring/ Summer 2005, pp. 138-168.

Yuen Chi-Lok (2008). Essays on air transport and public policy. PhD thesis, University British Columbia, Canada, 2008.